Pupillometry for Measuring User Response to Movement of an Industrial Robot

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ABSTRACT

Interactive systems can adapt to individual users to increase productivity, safety, or acceptance. Previous research focused on different factors, such as cognitive workload (CWL), to better understand and improve the human-computer or human-robot interaction (HRI). We present results of an HRI experiment that uses pupillometry to measure users' responses to robot movements. Our results demonstrate a significant change in pupil dilation, indicating higher CWL, as a result of increased movement speed of an articulated robot arm. This might permit improved interaction ergonomics by adapting the behavior of robots or other devices to individual users at run time.

CCS CONCEPTS

• **Human-centered computing** → **Ubiquitous and mobile computing systems and tools**.

KEYWORDS

pervasive eye tracking, human-robot interaction, pupil dilation, cognitive workload

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1 HUMAN-ROBOT INTERACTIONS AND PUPILLOMETRY

On manufacturing shopfloors, robots support productivity, relieving employees from monotonous and physically demanding tasks. In HRI, the acceptance of these new "colleagues" is an issue that needs to be addressed and ensuring *safe interactions with robots* is one of the extensively investigated considerations for robot acceptance. To ensure *physical safety*, industrial robots are required to incorporate safeguards such as protective force stops. During interaction, robots may also violate social conventions and norms and cause discomfort or stress for the operators, thereby affecting their cognitive activities and *psychological safety* [Lasota et al. 2017]. Furthermore, research has shown that robot acceptance is also related to specific movement behaviors, even in the case of interface-constrained articulated robot arms [Hostettler et al. 2022].

In human-computer interaction (HCI) and HRI literature, multiple objective (e.g., ocular, cerebral, dermal) and subjective metrics (e.g., questionnaires) were used to determine cognitive workload (CWL) and related factors (stress, arousal, frustration) that are mentally demanding for users [Kosch et al. 2023]. To enable robots to autonomously adapt to human preferences at run time, we require objective metrics that sense the human's state non-obtrusively and can be used as inputs for a system that improves physical and psychological interaction ergonomics.

Pupillometry describes the measurement of a person's pupil dilation in response to a stimulus. Various findings have shown that task difficulty is correlated with the CWL and pupillary responses [Iqbal et al. 2004; Kiefer et al. 2016; Kosch et al. 2023]. In HRI settings, changes of pupil diameter have demonstrated an inverse proportional relationship between trust and workload [Ahmad et al. 2019]. In addition, pupil dilation can be measured in a non-invasive manner as an indicator of the level of stress [Pedrotti et al. 2014]. Pupillometry and cognitive load can therefore be used as a *real-time input* for user-aware devices, and have been investigated in several HCI and HRI studies [Kosch et al. 2023]. We present the preliminary findings from a pilot HRI-experiment that demonstrate the effect of specific movements of an articulated robot arm on pupil dilation as an objective metric for stress-related factors such as CWL.

2 EXPERIMENTAL DESIGN, EARLY FINDINGS, AND OUTLOOK

We follow a within-subject design with robot behavior as the independent variable and pupil diameter as the dependent variable. We configured an xArm7 robot to move at 40% speed, then change its speed to 100%, and back to 40%, conforming to one of the movement parameters identified in [Hostettler et al. 2022]. Seven members (1 female) of our institute (2 with corrected vision) were recruited as the participants of our experiment. Due to the small sample size, we did not randomize the order of these conditions, though it is necessary for the follow-up study. Pupil data were recorded using the Pupil Core eye tracker [Kassner et al. 2014]. All participants were asked to sit in front of the robot with 1 meter distance from the robot's base (Figure 1). The ambient illumination conditions were controlled by closing blinds and ensuring constant room lighting.

We split the recordings into five phases: 1) pause before the movement, 2) slow, 3) fast, 4) slow, and 5) pause for post-movement.

*The first and second author contributed equally to this research.

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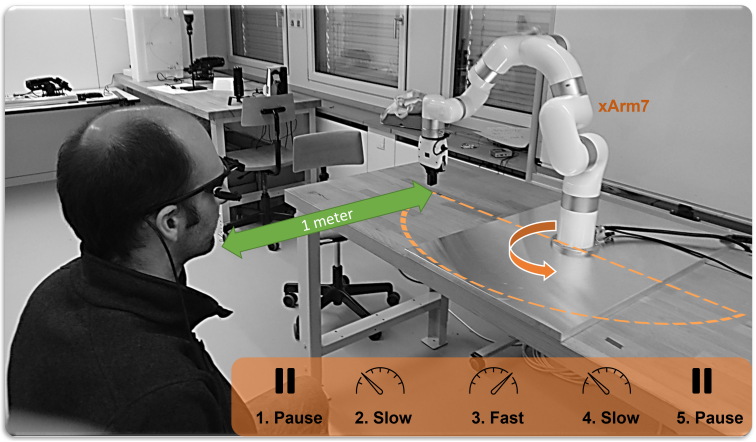


Figure 1: The experimental setup: Participant sitting 1m in front of the xArm7's base wearing the Pupil Core eye tracker.

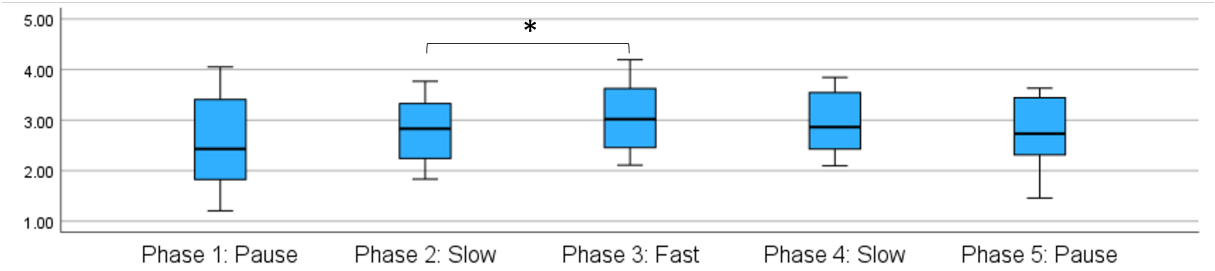


Figure 2: Average pupil diameter (in mm) in five phases: pause (1), slow (2), fast (3), slow (4), and pause (5). The difference in pupil diameter between the slow (2) and fast (3) phases is statistically significant (*).

The duration of each phase was 10 seconds. All participants verbally reported that they noticed the speed change from slow to fast and then back to slow. The analysis with repeated measures ANOVAs and Bonferroni correction revealed significant differences (CI: 95%) of pupil diameter between the 2nd (slow movement) and 3rd (fast movement) phases for left (p=.026) and right (p=.033) eye data (see Figure 2). The difference between the 3rd and 5th (fast to post-movement) phase is significant (p=.048) only for the left eye. No other inter-phase differences were significantly different.

In summary, our experimental setup tested how changes of robot speed affect pupil dilation as a metric for CWL. When observing the speed-change from slow to fast, participants' pupil consistently dilated, indicating a significant increase in CWL. We propose that pupil dilation is a valid metric to use as feedback for improving HRI ergonomics for individual users during interaction with an articulated robot arm.

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